High-resolution X-ray diagnostics of colliding wind interactions in massive binaries

G. Rauw[1], Y. Nazé[1], L. Mahy[1], E. Gosset[1] & M. De Becker[1,2]

[1]Institut d'Astrophysique et de Géophysique, Université de Liège, Belgium; [2]Observatoire de Haute Provence, France

Massive stars feature strong stellar winds with mass-loss rates of $10^{-6} - 10^{-4}$ M$_{Sun}$/yr and wind velocities of several thousand km/s. A number of open questions remain about these winds. Answering these questions is crucial for a better understanding of these important objects. In massive binary systems, the collision of the winds leads to the formation of a wind interaction zone (Fig. 1) where the kinetic energy is converted into heat. The dense post-shock plasma hence produces copious, hard (kT = 2 – 3 keV) thermal X-ray emission (Fig. 2).

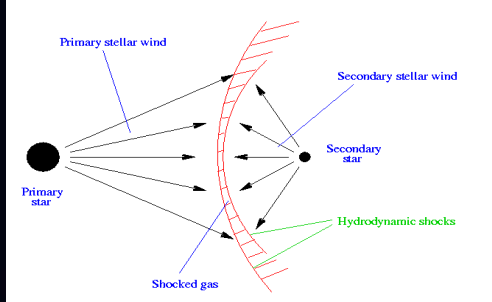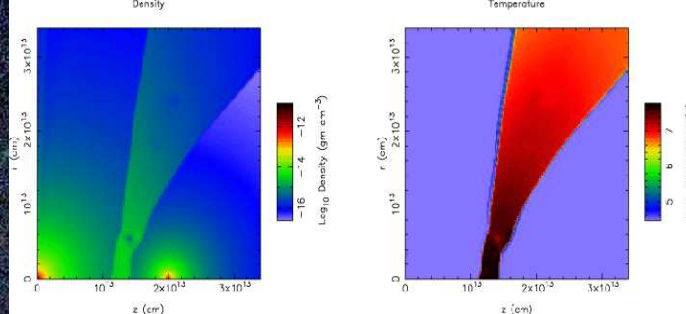Fig.1: Schematic view of the wind interaction zone in a massive binary system.

Fig.2: Hydrodynamical simulation of a colliding wind system. The left panel shows a map of the density , whilst the right panel yields the plasma temperature.

Interacting wind binary systems often feature a harder X-ray spectrum than single massive stars (as illustrated by the prominent Fe K line, see Fig. 3) and display flux and spectral variability as a function of orbital phase (due to the modulation of the line of sight column density or the changing separation in eccentric systems) : e.g. Cyg OB2 #8a (O6If + O5.5III(f), P = 21.9 days, e=0.24, De Becker et al. 2006, MNRAS 371, 1280, see Fig. 3).
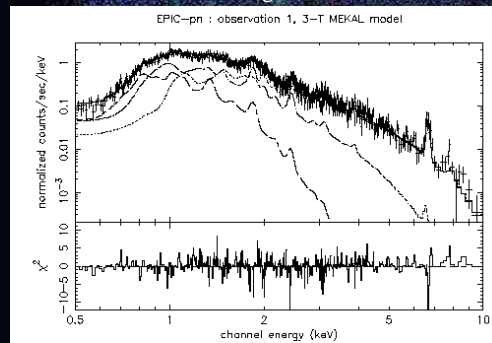

Fig.3: EPIC-pn spectrum of Cyg OB2 #8a at phase 0.53. Note the prominent Fe K line.

Much insight into the physics of stellar winds and shocks can be gained by studying the properties of the shock heated gas and the radiative cooling in the post-shock region. This can be achieved using the Doppler tomography technique, (Fig. 4) widely used in the optical domain e.g. to map the Hα emission region in colliding wind binaries (see e.g. Rauw et al. 2006, A&A 432, 985; see Fig. 5) .
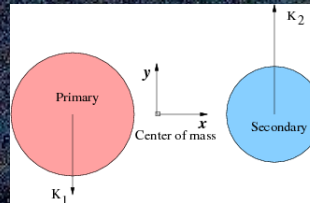

Fig.4: Coordinates used in the Doppler tomography technique to map a stationary (in the frame of reference of the binary) X-ray emission zone. For an observer, the radial velocity of this emission zone changes with orbital phase φ as :

$$v(\phi) = -v_x \cos(2\pi\phi) + v_y \sin(2\pi\phi) + v_z$$

Numerical simulations (Henley et al. 2003, MNRAS 346, 773) predict strong phase-locked profile variability for the X-ray lines formed inside the wind interaction zone. Doppler mapping of the variations of the Fe K line will enable us to determine the properties of the hottest plasma in the interaction zone. These information are especially important for a better understanding of the hydrodynamics of stellar winds (radiative cooling, modified shocks due to particle acceleration,...). Current X-ray observatories lack both the sensitivity and the spectral resolution (@ 6 keV) to perform these studies. With a resolving power of about 2500 @ 6 keV and its large effective area, the XMS instrument onboard IXO will enable the very first studies of this kind and shed new light on the physics of stellar winds.
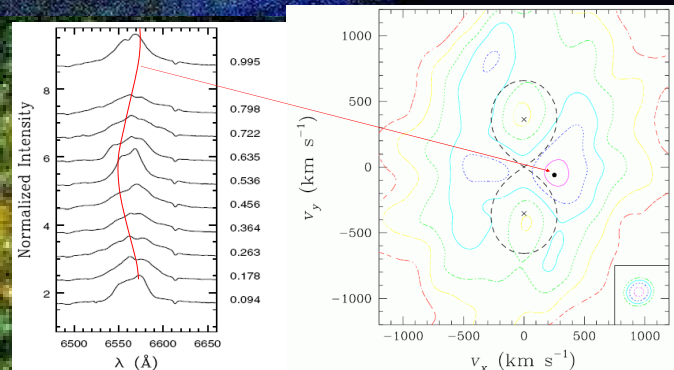

Fig.5: Left panel: observed line profile variations of the Hα line in the interacting wind system WR20a (WN6ha + WN6ha). The red sine wave illustrates the radial velocity of a specific emission region which corresponds to the highest peak in the Doppler map shown on the right.

Conclusions: The existing X-ray observatories revealed many aspects of the wind interaction processes in massive binary systems. However, a more detailed analysis, allowing to put constraints on the hydrodynamical processes in stellar winds, has to await the capabilities of IXO and of instruments such as XMS, offering high spectral resolution along with a large collecting area at the energy of the Fe K line. Mapping the Fe K line emission region of interacting wind binaries in velocity space by means of a Doppler tomography technique will provide highly important information about the physics of stellar winds in general and the properties of hydrodynamical shocks in particular.